National Aeronautics and Space Administration

TA 1: Launch Propulsion Systems

1.6 Balloon Launch Systems – Follow-up

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NASA GSFC's WFF

David Pierce
Senior Program Executive for
Suborbital Research, NASA HQ

Follow-up from NRC

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- What information does NASA have regarding the expected benefit of proposed improvements in balloon technologies compared to the capabilities of sounding rockets, high-altitude unmanned aircraft, cubesats, and smallsats in terms of the types of missions that could be flown, scientific return, affordability, risk, etc.? The desired comparison would consider the current state of the art as well as potential improvements that could arise from investments in technologies related to each of these systems.

SMD's Research Program

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- Conducting strategically planned and competed Earth and Space science flight program investigations.
- Developing precursor instrument technologies for future science measurements.
- Developing and demonstrating new carrier technologies and capabilities to enable NASA's missions.
- Conducting R&T, providing suborbital launch opportunities to the U.S. science community. Calibration/validation of satellite measurements.
- Fostering Innovation across NASA/community. Promoting STEM and inspiring students through hands-on student flight research missions.

Cutting Edge Scientific Research

Hands-on Student Educational flight Projects

Technology Maturization

Calibration/Validation of Satellite Measurements

Science @ NASA executes:

- 95 missions
- 121 spacecraft
- 12 Balloon launches (FY 2015)
- 20 Sounding rockets (FY 2015)
- 4,200 Airborne hours (FY 2015)

SMD Missions utilize the spectrum of observing regimes

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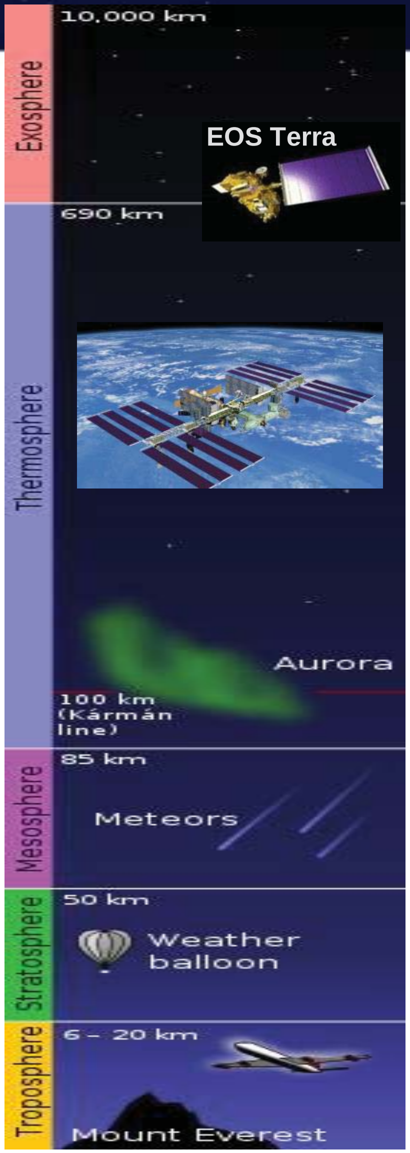
SMD is Science Driven, not Platform Driven

- Proposed investigations undergo a competitive science/merit and feasibility external peer review.
- The PI proposes the platform as part of the proposal. SMD does not appoint the carrier for the investigator.
- SMD offers STMD commercial suborbital vehicles along with the NASA/SMD managed “core vehicles”.

- ***SMD community develops science, technology and people along a continuum from the lab to the suborbital platform to the orbital flight project.***



ISS & Satellites (months - years)

Sounding Rockets
(20 Min)

sRLVs (10 min)

Scientific Balloons (1- 60 days)

Aircraft/UAS/SOFIA (4-30 hrs)

Science Platforms

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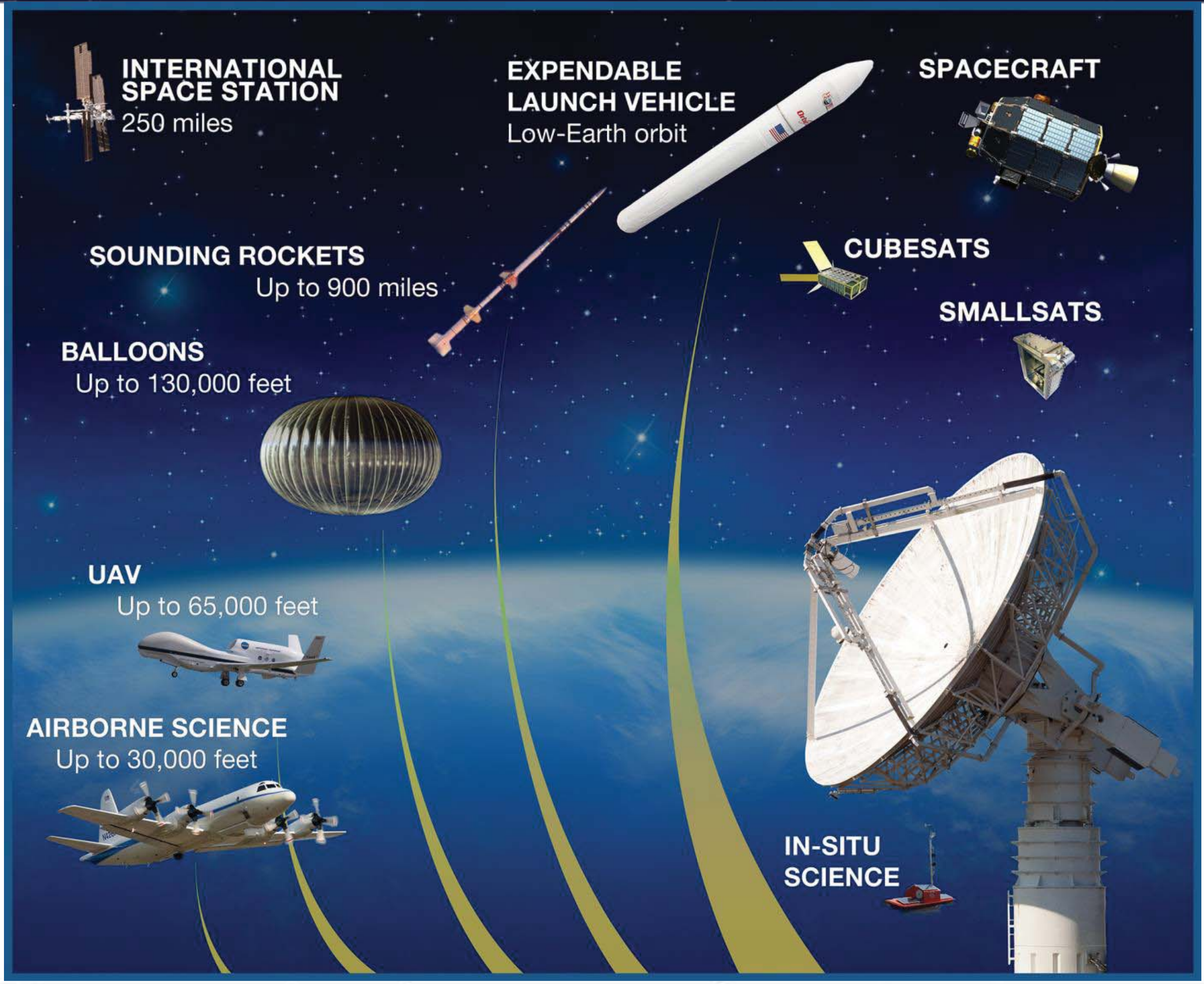

NASA Airborne Science

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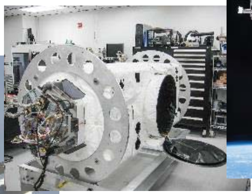
- ***NASA's Airborne Science Program (ASP) conducts frequent global aircraft investigations in support of the NASA Earth Science community.***
  - Advance Earth System Science
  - Field Campaigns to complement Satellite Measurements
  - Developing technologies to improve Earth Observation capabilities.

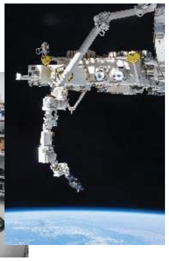
- ***Aircraft Offices: ARC, DFRC, GSFC/WFF, GRC, JSC, LaRC***
  Altitudes: up to 21 km; Duration: up to 30 hr

- <u>FY2015</u>: Conducted 4200 flight operation hours (>20 missions/deployed field campaigns), utilizing more than 15 NASA aircraft and UASs.

Antarctic Peninsula (M. Studinger)

Cloud Physics Lidar (CPL) flew on the ER-2





CPL was precursor to the Cloud-Aerosol Transport System (CATS) on ISS

Scientific Balloons

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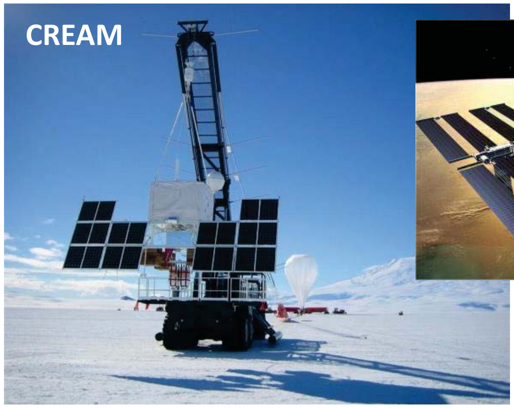
- **The NASA Balloon Program provides near space access at a fraction of the cost of a satellite.**
- **Project Office: GSFC/WFF**
- 15 launches per year
- Float altitudes: 30-45 km
- Large payload volumes
- Payloads masses up to 3600 kg
- Mission durations up to 50 days (100 days planned)

<u>Carrier Technologies driven by the Science Community</u>

- Higher data-rate telemetry.
- Finer Pointing: Sub arc-second pointing
- Longer Flights (> 60 days) super pressure balloon capable of one hundred day missions (in development toward 100 days, any latitude)



Zero Pressure Balloons

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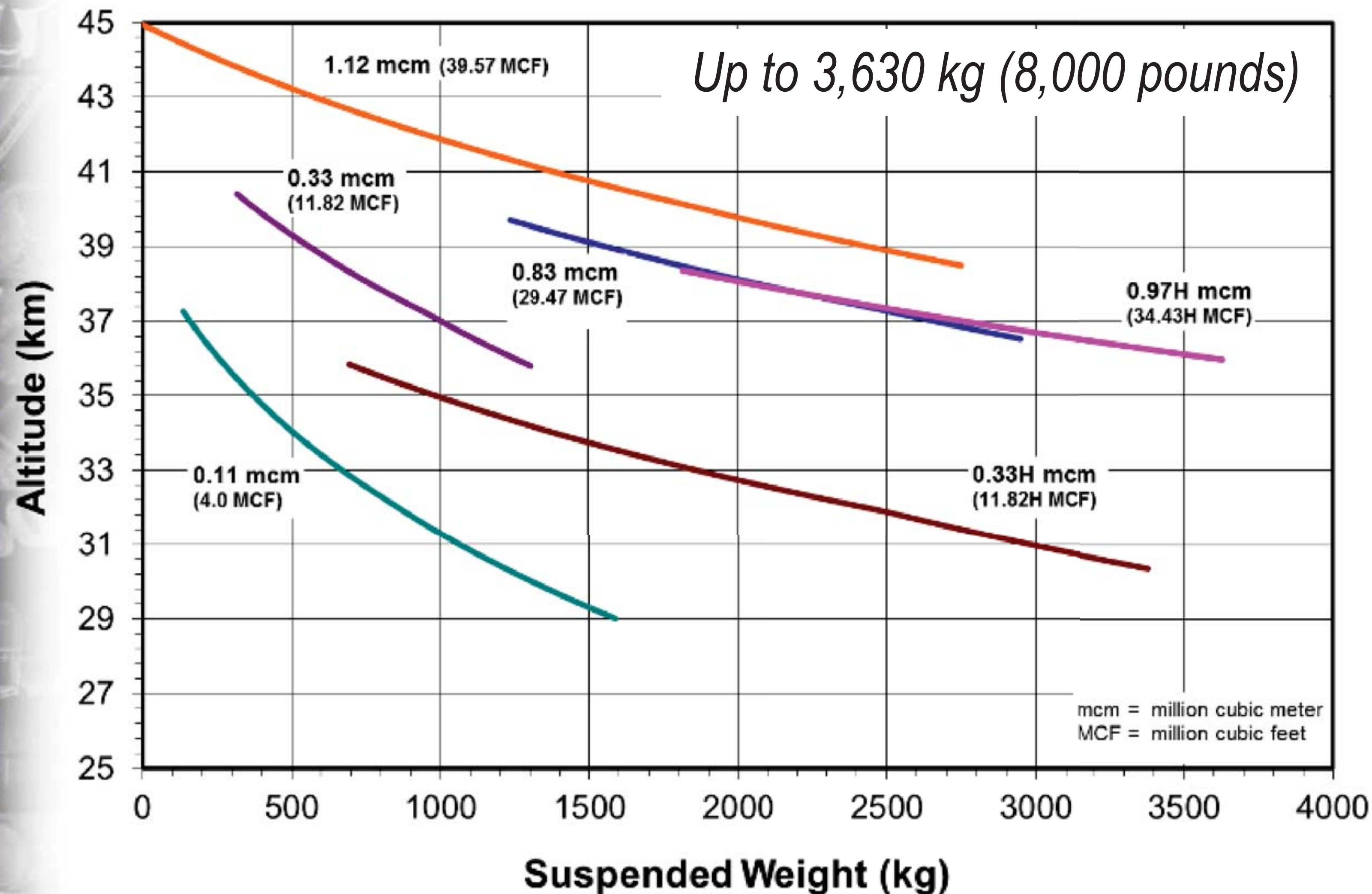
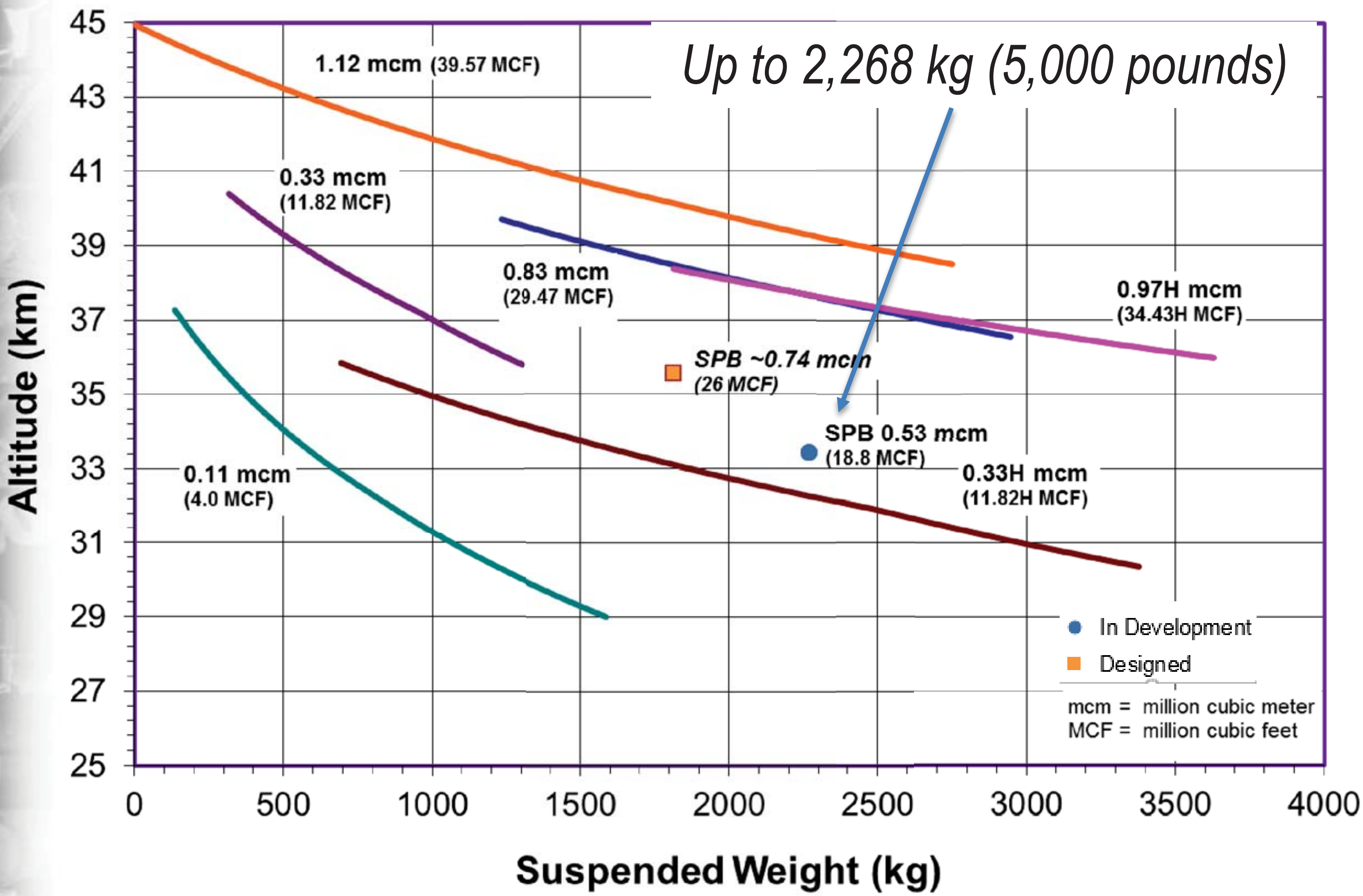


Super Pressure Balloons

National Aeronautics and Space Administration



Sounding Rockets

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- Program Office: GSFC/WFF
- Payload capabilities
  - Masses up to ~600kg
  - Sub arc-second pointing
  - Diameters limited to <1m
- Apogee altitudes between 100-1400km
  - Up to 20 minutes of ballistic flight
- Supports complex & hazardous payloads
  - Deployable & multi bodies
  - Chemical deployments
  - Advanced Technology demonstrations

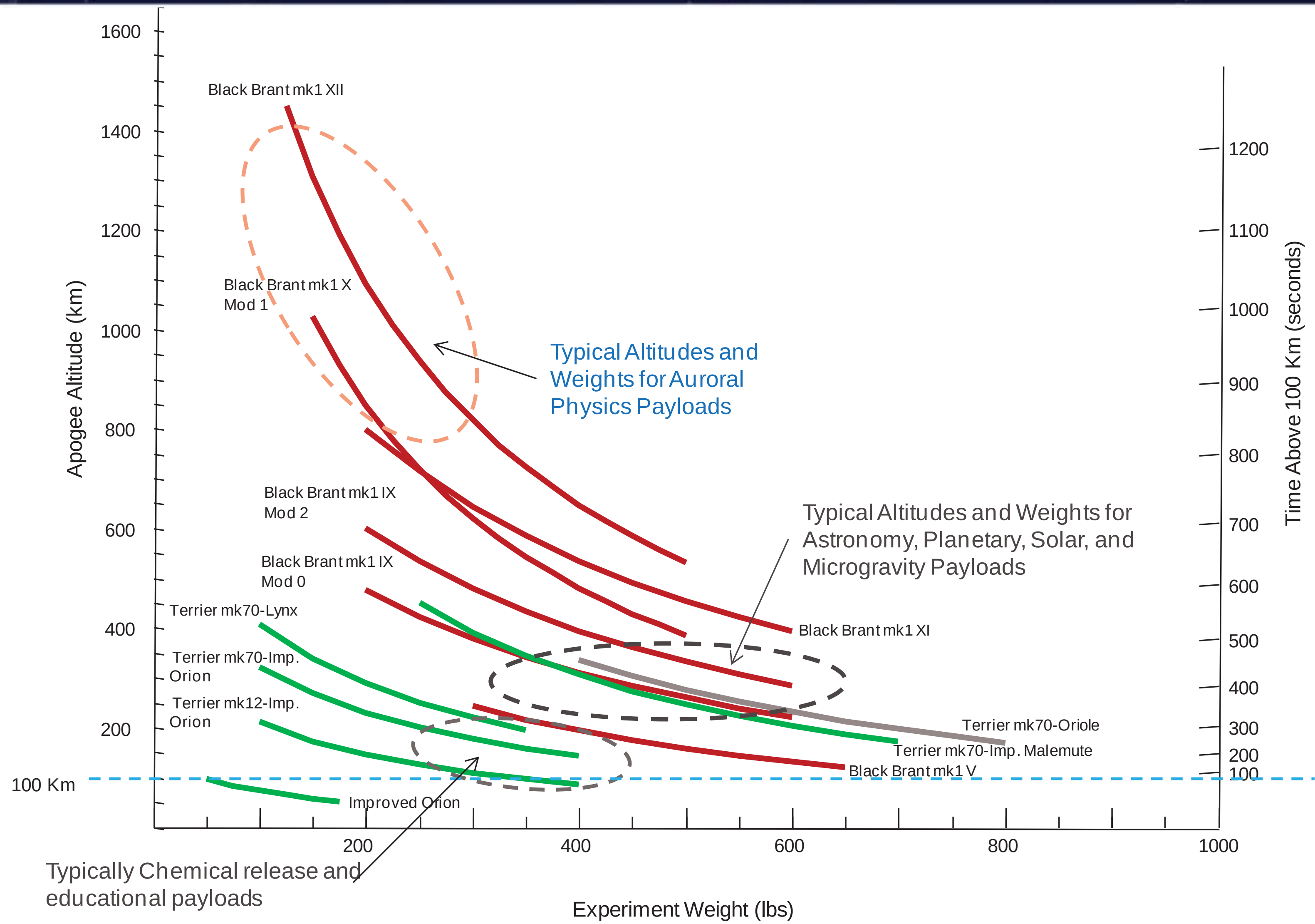
- <u>FY2015:</u> NASA conducted 20 rocket launches during 5 launch campaigns

Sounding Rocket on Launcher

IRVE Demonstration

Sounding Rocket Performance

National Aeronautics and Space Administration



Suborbital Research Program Utilization

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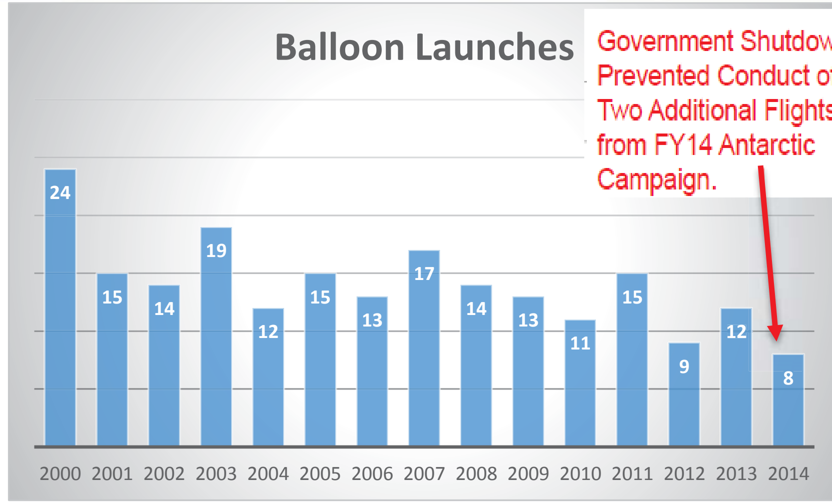
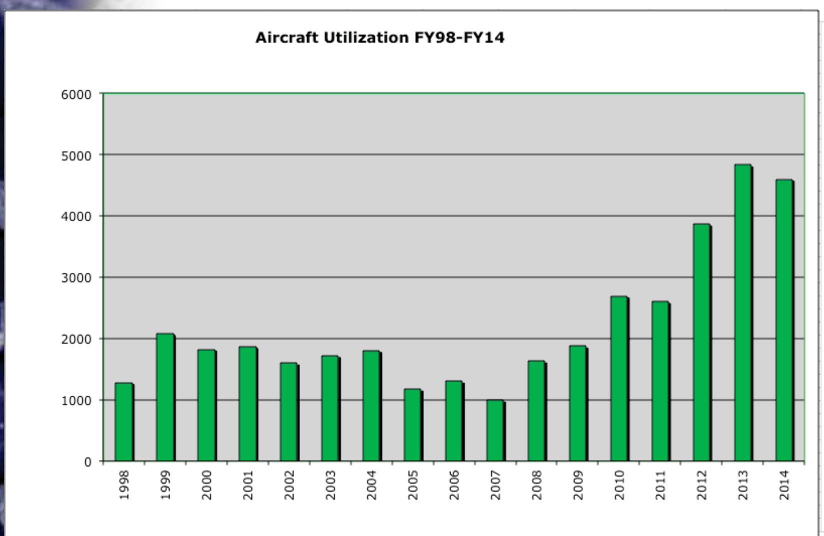
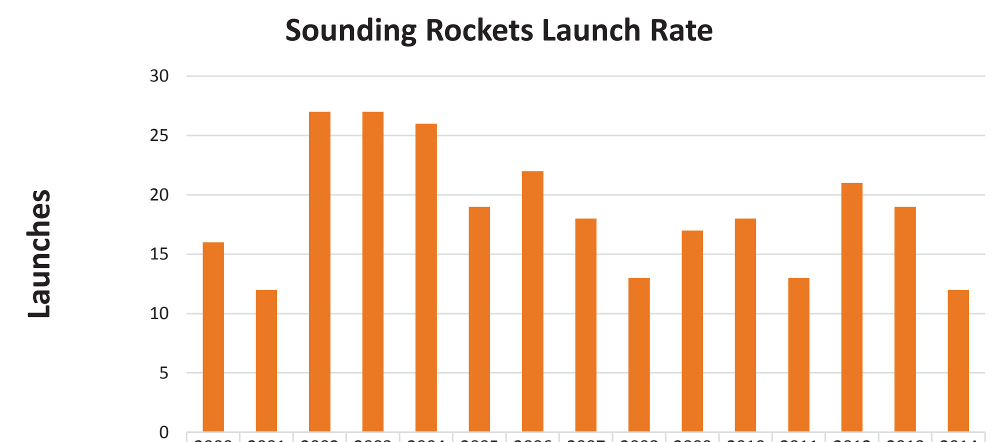
- Balloon launches in FY14 affected by Gov't shutdown (cancellation of Antarctic campaign). Decadal average is 13 launches, with an average 29 funded missions/year.
- Sounding Rocket Decadal average is 17 launches, with an average of 42 funded missions/year.
- Airborne science flight hours have increased 114% over past 4 years.







	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
TOTAL	16	12	27	27	26	19	22	18	13	17	18	13	21	19	12

SMD Balloon missions have contributed in essential ways to NASA spacecraft missions.

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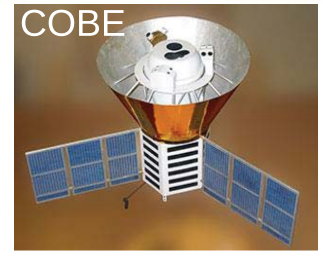
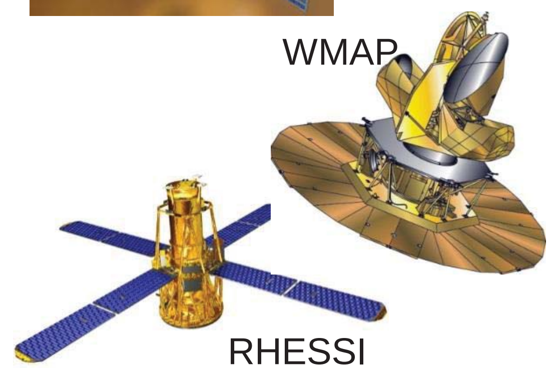
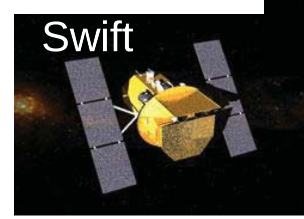
- ***Over 30 spacecraft instrument in the last 4 decades first flew on balloons.***
- Balloon flights of the differential radiometer and Far IR spectrum of the CMB laid the critical ground work for the design of instruments for **COBE** and **WMAP**.
- Detectors on the **RHESSI** mission were first developed and demonstrated on balloon-borne instruments.
- The scintillating fiber trajectory detector on the **ACE** Cosmic Ray Isotope Spectrometer was demonstrated first in a balloon flight.
- On the **EOS-Aura satellite** to study the atmosphere's chemistry and dynamics, the MLS, TES, and HIRDLS instruments all trace their heritage to instruments that first flew on balloons.
- GSFC In-Focus Balloon flights of the cadmium-zinc-telluride CZT array led to the design the **Swift** Burst Alert Telescope (BAT) instrument.
- Balloon flights developed precursor instrumentation for ISS payloads **CALET**, **CREAM**, and **JEM-EUSO**







SMD Aircraft missions that have led to the development of Earth Science spacecraft instruments

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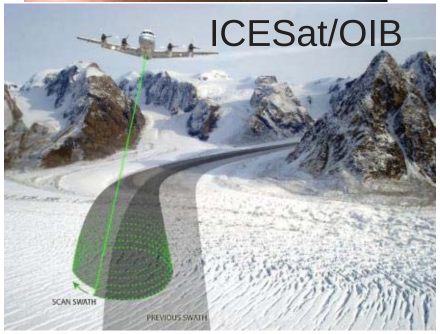
- Aircraft flights in the 80's and 90's led to the GSFC laser altimetry design of the Mars Orbiter Laser Altimeter, or MOLA on the **Mars Global Surveyor** and the **Lunar Orbiter Laser Altimeter (LOLA)**.
- LaRC aircraft flights developed precursor SAGE instruments
- Laser altimetry by the **WFF Airborne Topographic Mapper (ATM)** started to map the height of the ice caps operationally in 1993 and has since then provided the data set that first showed the loss of the Greenland ice mass and is the primary instrument for **Operation IceBridge**.
- ATM was also critical for the development of **ICESat** and will be a key instrument for **ICESat-2** cal/val efforts. The 20+ year ATM Greenland time series is baseline data set for all cryospheric missions and science efforts.
- Aircraft flights of the MODIS Airborne Simulator (MAS) MASTER, AirMISR and MOPITT instruments lead to the MODIS, MOPITT and MISR instruments on the **EOS- Terra and Aqua satellites.**
- The Cloud-Aerosol Lidar on the **CALIPSO/CloudSat** satellite was demonstrated first on NASA aircraft flights.



Unmanned Aerial Vehicle - Global Hawk

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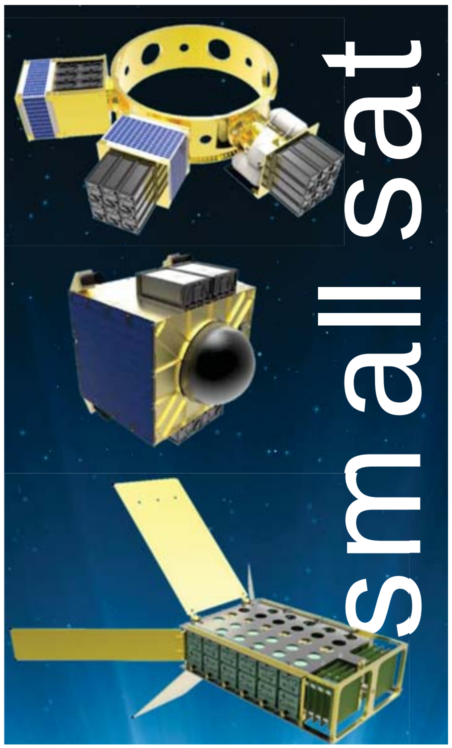
The Global Hawk is NASA's high altitude unmanned aerial platform. Reaching altitudes of 18.3 km (60,000 feet) the vehicle has a 8,500 nautical mile range and 24-hour endurance. The 13.4 m (44 foot) long Global Hawk has a wingspan of more than 35.4 m (116 feet), a height of 4.6 m (15 feet), and a gross takeoff weight of 12,133 kg (26,750 pounds), including a 680 kg (1,500-pound) payload capability.

http://www.nasa.gov/centers/armstrong/news/FactSheets/FS-098-DFRC.html
http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104516/rq-4-global-hawk.aspx

SmallSats and CubeSats



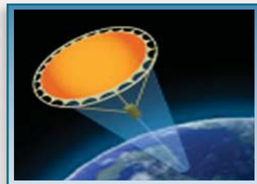
- Cube Sats began as low cost student platforms, and are evolving into low cost platforms for scientific research in Heliophysics, Astrophysics, and Planetary Science
- Current plans include launches from ISS; deployment at the moon, Mars, and beyond.
- Communication evolving from UHF to X/S band and lasercom
- Constellations of CubeSats can create distributed networks that can do the work of a large satellite at a fraction of the cost.
- Standardized architectures, communications, and power are still evolving.

NASA's Earth Science Technology Office (ESTO)

The Earth Science Technology Office (ESTO) is a ***targeted, science-driven, competed, actively managed, and dynamically communicated technology program*** and serves as a model for technology development.

Competitive, peer-reviewed proposals enable selection of best-of-class technology investments that ***retire risk*** before major dollars are invested: a cost-effective approach to technology development and validation. ESTO investment elements include:

Observation



Instrument Incubator Program (IIP)
provides robust new instruments and measurement techniques (TRL 3-6)

16 active projects; total funding ~$85M over 3 years; new solicitation now open

Advanced Component Technologies (ACT)
provides development of critical components and subsystems for instruments and platforms
TRL 2-5; *15 active projects; total funding ~$16M over 3 years*

Information

Advanced Information Systems Technology (AIST)
provides innovative on-orbit and ground capabilities for collecting, processing, and management of remotely sensed data and the efficient generation of data products
TRL 2-6; *18 active projects; total funding ~$39M over 3 years*

Validation

In-Space Validation of Earth Science Technologies (InVEST)
provides in-space, orbital technology validation and risk reduction for small instruments and components (in lieu of ground/aircraft testing) TRL 5-7;*First awards imminent*

SMD Sponsored CubeSat Missions

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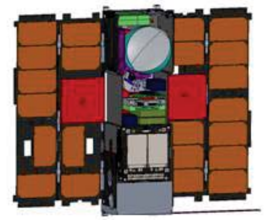
SMD is selecting cubesat investigations across its four science disciplines to enable scientific discovery, develop precursor spaceflight technologies, and to foster hands-on student flight research.

Year Selected	Sponsor	Mission	PI	Institution	Size	Solicitation	Access to Space	Status
2012	ESD/ESTO	MCubed-2	Cutler	Michigan/JPL	3U	ESTO	CSLI (2014)	launched
2012	ESD/ESTO	GRIFEX	Rider	JPL/Umich	3U	ESTO	CSLI (2012)	launched
2013	ESD/ESTO	MiRaTA	Blackwell	MIT	3U	ROSES/InVEST	CSLI (2014)	LRD 2016
2013	ESD/ESTO	RAVAN	Dyrud	JHU/APL	3U	ROSES/InVEST	CSLI (2014)	LRD 2016
2013	ESD/ESTO	LMPC	Fields	Aerospace	3U	ROSES/InVEST	CSLI (2014)	LRD 2016
2013	ESD/ESTO	HARP	Martins	UMBC	3U	ROSES/InVEST	CSLI (2013)	LRD 2016 (ISS)
2013	PSD	INSPIRE	Klesh	JPL	3U	Planetary	CSLI (2014)	LRD 2017
2013	HPD/HTiDES	CERES	Kanekal	GSFC	3U	ROSES	CSLI (2014)	LRD NET 2017
2014	ESD	IceCube	Wu	GSFC	3U	ROSES	CSLI (2013)	LRD 2016
2014	HPD/HTiDES	TBEx	Tsunoda	SRI	3U	ROSES	CSLI (2015)	LRD 2017
2014	HPD/HTiDES	MinXSS	Woods	U Colo	3U	ROSES	Orb-4/NanoRacks	LRD Dec 2015
2014	HPD/HTiDES	SORTIE	Crowley	ASTRA	6U	ROSES	TBD	TBD
2014	HPD/HTiDES	ELFIN-STAR	Angelopoulos	UCLA	3U	ROSES	CSLI (2014)	LRD 2017
2015	HPD/HTiDES	CuSP	Desai	SwRI	6U	ROSES	EM-1	LRD 2018
2015	APD	Halo-Sat	Kaaret	U Iowa	6U	ROSES	TBD	LRD 2018
2015	PSD	LunaH-Map	Hardgrove	ASU	6U	ROSES	EM-1	LRD 2018
2015	PSD	Q-PACE	Colwell	UCF	2U	ROSES	CSLI (2015)	TBD
2015	ESD/ESSP	TEMPEST-D	Reising	Colo State U	6U	EVi-2	CSLI (2015)	LRD 2018
2015	ESD/ESTO	CubeRRT	Johnson	OSU	6U	ROSES/InVEST	TBD	TBD
2015	ESD/ESTO	CIRiS	Osterman	BA&TC	6U	ROSES/InVEST	TBD	TBD
2015	ESD/ESTO	CIRAS	Pagano	JPL	6U	ROSES/InVEST	TBD	TBD
2015	ESD/ESTO	RainCube	Peral	JPL	6U	ROSES/InVEST	TBD	TBD

Highlighted (ESTO/InVEST) Technology Investigations

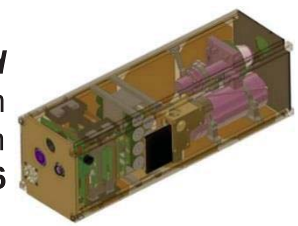
The need to space-validate new technologies is critical to reduce risk for future Earth science measurements. The In-Space Validation of Earth Science Technologies (InVEST) program is intended to fill the gap. The first InVEST solicitation sought small instruments and subsystems that advance technology to enable relevant measurements and targeted the CubeSat platform.

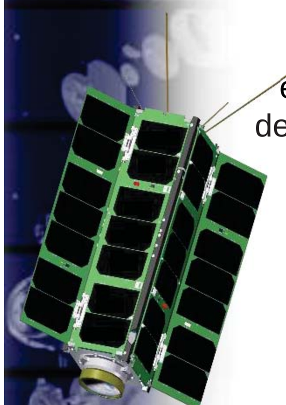
The ***Microwave Radiometer Technology Acceleration (MiRaTA) Cubesat*** will validate multiple subsystem technologies and demonstrate new miniature microwave radiometers operating near 52-58, 175-191, and 206-208 GHz that could dramatically enhance the capabilities of future temperature and humidity measurements. - K. Cahoy, MIT; **Launch NET 2016**



The ***Radiometer Assessment Using Vertically Aligned Nanotubes (RAVAN)*** project will demonstrate a bolometer radiometer that is compact, low cost, and absolutely accurate to NIST traceable standards. RAVAN could lead to affordable CubeSat constellations that, in sufficient numbers, might measure Earth's radiative diurnal cycle and absolute energy imbalance to climate accuracies (globally at 0.3 W/m2) for the first time. - W. Swartz, JHU/APL; **Launch NET 2016**

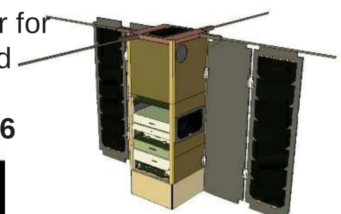
The objective of the ***Cubesat Flight Demonstration of a Photon Counting Infrared Detector (LMPC CubeSat)*** is to demonstrate in space, a new detector with high quantum efficiency and single photon level response at several important remote sensing wavelength detection bands from 1 to 2 microns. - R. Fields, Aerospace Corporation; **Launch NET 2016**

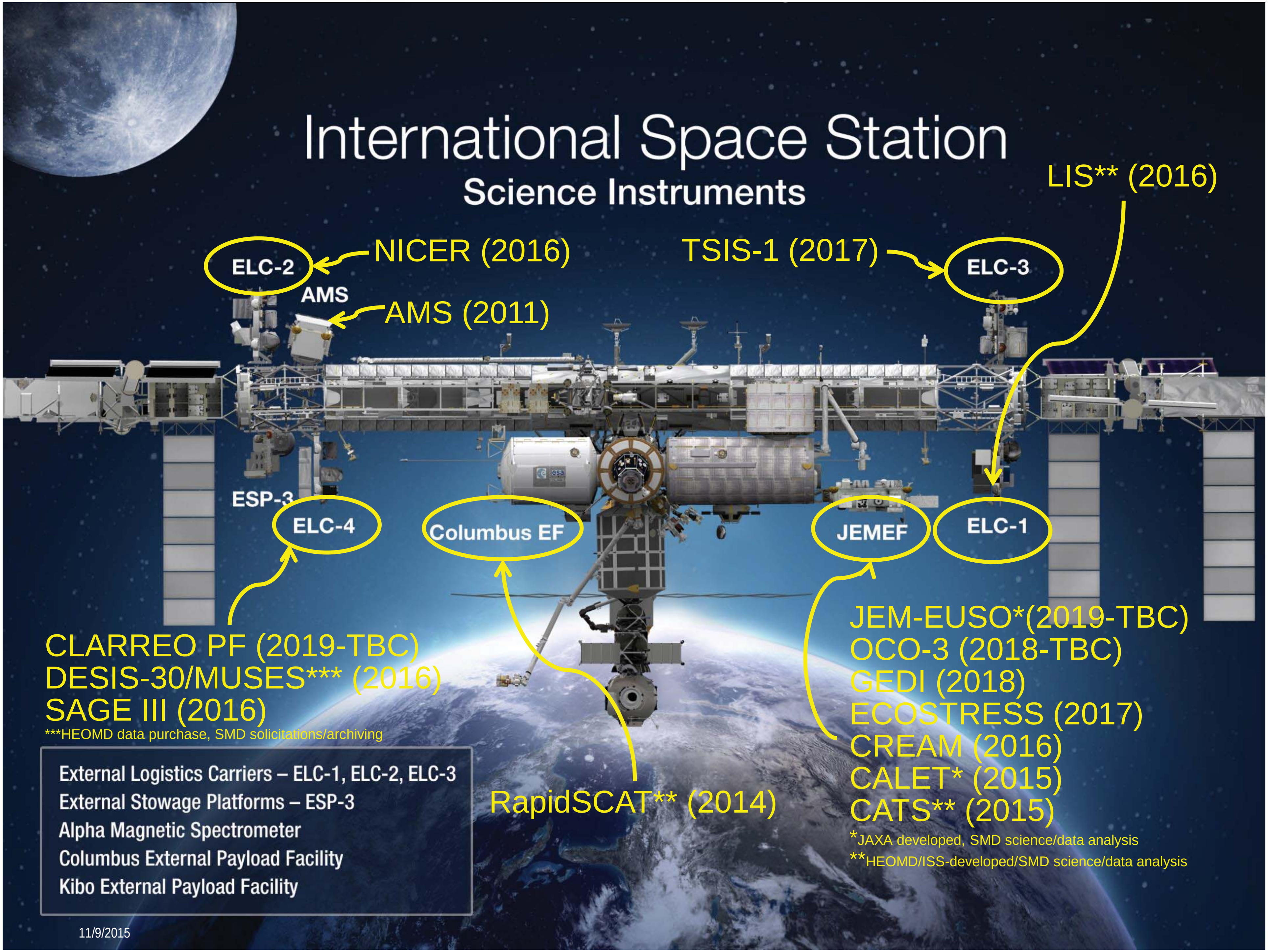




The ***HyperAngular Rainbow Polarimeter HARP-CubeSat*** will validate a technology required by the Aerosol-Cloud-Ecosystem (ACE) mission concept and prove the capabilities of a highly-accurate, wide-FOV, hyperangle, imaging polarimeter for characterizing aerosol and cloud properties.
- J. V. Martins, UMBC; **Launch NET 2016**

IceCube is a three unit (3U) CubeSat under development to validate a 874-GHz radiometer receiver for future use in ice cloud measurement missions. This submillimeter wave radiometer technology could directly benefit an ice cloud imaging radiometer such as that called for by the Aerosol-Cloud-Ecosystem(ACE) mission concept. - D. Wu, NASA Goddard Space Flight Center; **Launch NET 2016**




International Space Station
Science Instruments
LIS** (2016)
NICER (2016)
TSIS-1 (2017)
ELC-2
ELC-3
AMS
AMS (2011)
ESP-3
ELC-4
Columbus EF
JEMEF
ELC-1
JEM-EUSO*(2019-TBC)
OCO-3 (2018-TBC)
GEDI (2018)
ECOSTRESS (2017)
CREAM (2016)
CALET* (2015)
CATS** (2015)
*JAXA developed, SMD science/data analysis
**HEOMD/ISS-developed/SMD science/data analysis
CLARREO PF (2019-TBC)
DESIS-30/MUSES*** (2016)
SAGE III (2016)
***HEOMD data purchase, SMD solicitations/archiving
RapidSCAT** (2014)
External Logistics Carriers – ELC-1, ELC-2, ELC-3
External Stowage Platforms – ESP-3
Alpha Magnetic Spectrometer
Columbus External Payload Facility
Kibo External Payload Facility
11/9/2015

ISS Science Payloads

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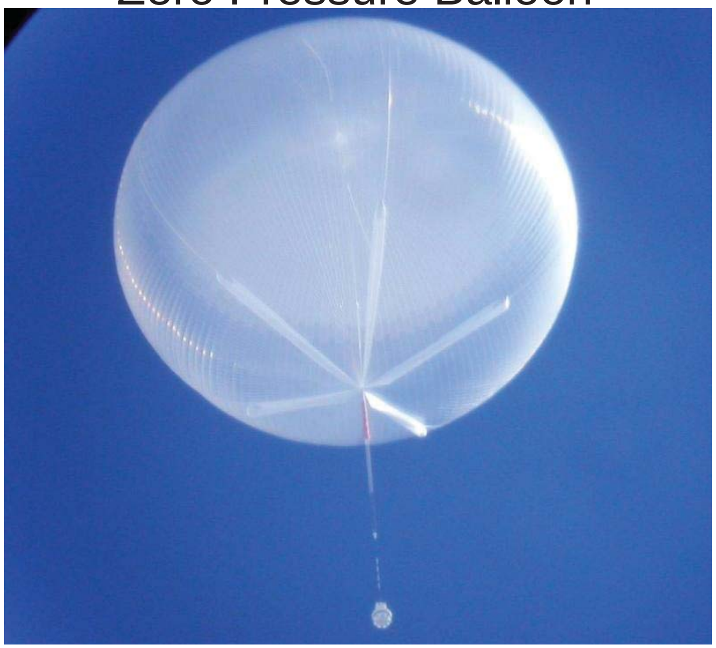
Mission	Primary Sponsor	PI Institution	Discipine	Acquisition	Launch Date	ISS Location	Mission Duration
AMS-02	DOE-SMD	MIT	Astrophysics	Directed	May 16 2011	S3 Truss	EOL ISS
CREAM	SMD-APD	UMD	Astrophysics	SMD Competed	August, 2016	JEM-EF (2)	36 Months
NICER	SMD-APD	GSFC	Astrophysics	SMD Competed	February, 2017	ELC-?	18 Months
CALET	JAXA/SMD-APD	Waseda Univ	Astrophysics	JAXA developed	August 15 2015	JEM-EF (9)	48 Months
JEM-EUSO	JAXA/SMD-APD	U Chicago	Astrophysics	JAXA developed	> 2019	JEM-EF (9)	EOL ISS
CATS	HEOMD ISSNL	GSFC	Earth Science	SMD-Ops	January 6 2015	JEM-EF	31 Months
LIS	DoD/STP-H5; SMD	MSFC/UAH	Earth Science	SMD-Ops	February, 2016	ELC-1	24 Months
HICO	NRL/ONR;HEOMD ISSP	NRl/NASA/	Earth Science	SMD-Ops	September, 2009	JEM-EF	60 Months
GEDI	SMD-ESD/ESSP	UMD	Earth Science	SMD Competed	March, 2019	JEM-EF	12 Months
ECOSTRESS	SMD-ESD/ESSP/EVI-2	JPL	Earth Science	SMD Competed	March, 2017	JEM-EF (10)	12 Months
SAGE III	NASA/RSA	LaRC/JSC/ISSP	Earth Science	Directed	February, 2016	ELC-4	36 Months
OCO-3	SMD-ESD/ESSP	JPL	Earth Science	SMD Competed	December, 2016	JEM-EF	36 Months
TSIS-1	NOAA / SMD	UC/LASP	Earth Science	Directed	August, 2017	ELC-3	36 Months
RapidScat	HEOMD ISSP	JPL	Earth Science	SMD-Ops	September 20 2014	Columbus EPF	36 Months

CY	11	12	13	14	15	16	17	18	19	20
AMS-02										
HICO										
CALET										
CATS										
RapidScat										
LIS										
SAGE III										
OCO-3										
CREAM										
NICER										
ECOSTRESS										
TSIS-1										
GEDI										
JEM-EUSO										

Balloon Technologies

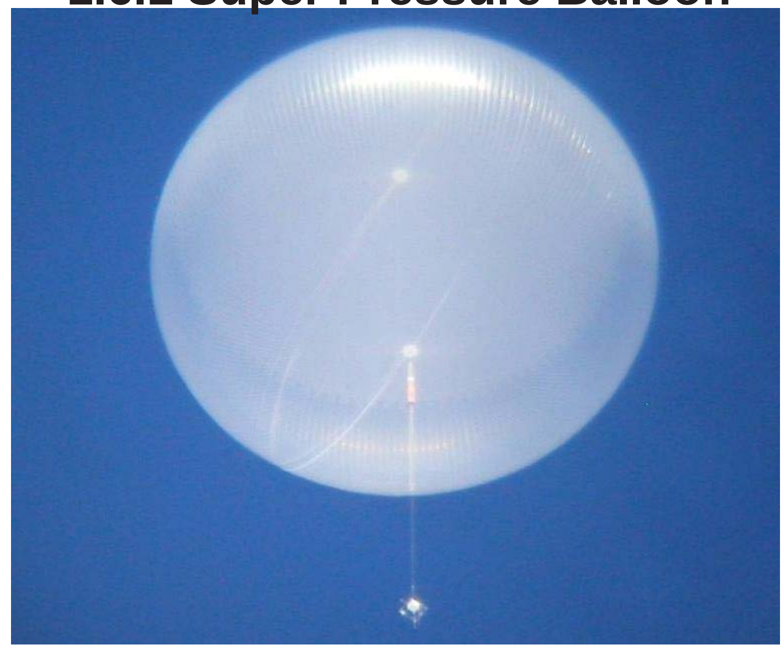
National Aeronautics and Space Administration

State of the Art:
Zero Pressure Balloon



1.6.2 Materials
1.6.3 Pointing Systems
1.6.4 Telemetry Systems
1.6.5 Balloon Trajectory Control
1.6.6 Power Systems
1.6.7 Mechanical Systems: Launch Systems
1.6.8 Mechanical Systems: Parachute

Technology Development:
1.6.1 Super Pressure Balloon



1.6.2 Materials
1.6.3 Pointing Systems
1.6.4 Telemetry Systems
1.6.5 Balloon Trajectory Control
1.6.6 Power Systems
1.6.8 Mechanical Systems: Parachute
1.6.9 Mechanical Systems: Floatation

Cosmic Microwave Background

National Aeronautics and Space Administration

- Mid-latitude balloon-borne observations are the single best platform (including ground-based telescopes from, for example, Chile) for measurements of CMB polarization whose science aim is to constrain the optical depth to reionization. This cannot be done from the south pole, or from the Antarctic LDB, because polar studies require nearly full sky coverage which can only be had from mid-latitudes.

- The mid-latitude SPB is the only platform that provides nearly full sky coverage for more than one night. Even Kiruna, Sweden flights cannot provide a significant amount of flight time without Russian overflight.

- The science drivers for the measurements are broad, and include early universe physics as well as the neutrino sector.

Optical

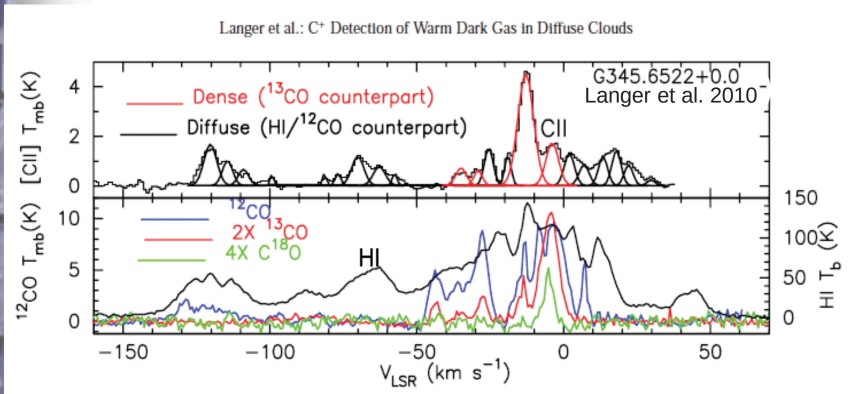
- The SPB is the only platform that offers a persistent capability in the near UV and IR. Flights of 30 to 100 nights offer a unique capability to provide wide-field, sub-arcsecond imaging in the UV to near IR. The recent test flight of SuperBIT demonstrated 150 milli arc second stability of the point spread function (PSF) with a prototype optical system, which will be improved upon with SuperBIT SPB. Once the Hubble is no longer available (ie, any moment), there will be no facility other than SPB capable of this.

- The science opportunities for this are myriad, but include imaging in the near UV to support the photometric capabilities of the large ground-based surveys (like HyperSuprimeCam, etc), as well as the flagship missions like Euclid and AFTA. Wide field surveys with highly stable PSFs offer opportunities in weak and strong lensing studies, which is the focus of SuperBIT.

Explorer MoO: GUSTO

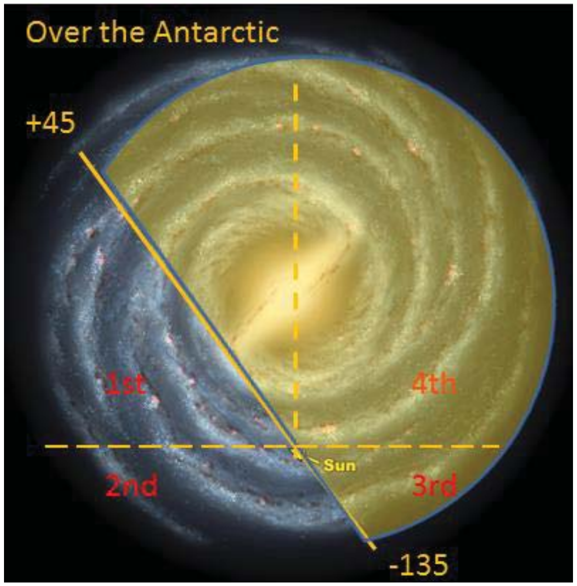
National Aeronautics and Space Administration

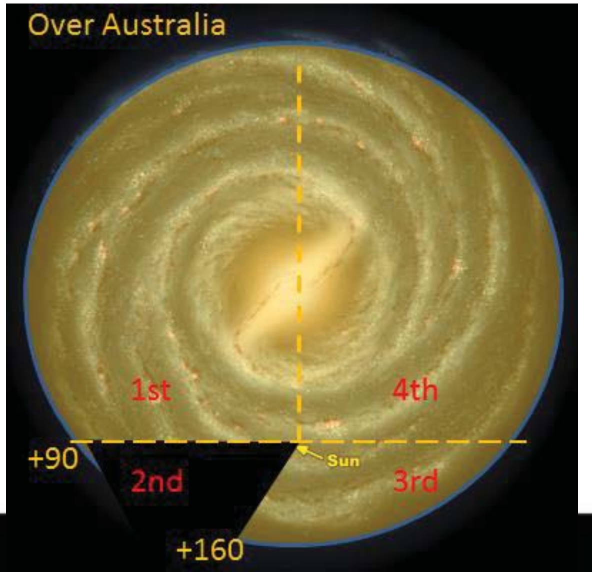
Observation Objectives: [CII], [OI], & [NII] Surveys of MW and LMC

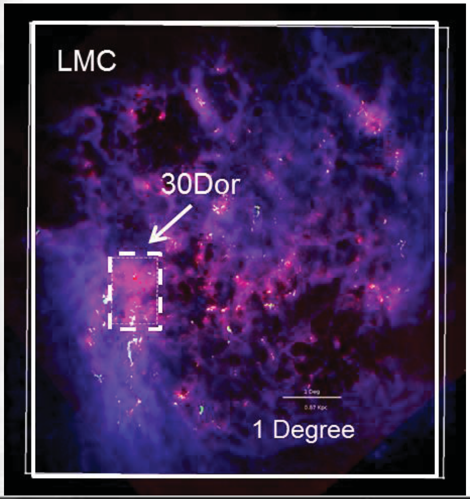


Above: Single line of sight (LOS) spectra of [CII] (*Herschel)* taken toward a Galactic sources. *GUSTO 's* surveys will observe **<u>~100,000 LOS.</u>**

GUSTO Galactic Plane Visibility:







The Large Magellanic Cloud (LMC) in HI (blue), CO (green), *Spitzer* 160µm emission (Red). The <u>solid box</u> represents the area for the large–scale mapping with GUSTO. The <u>dashed</u> are the proposed deep integration maps.

Explorer MoO: GUSTO

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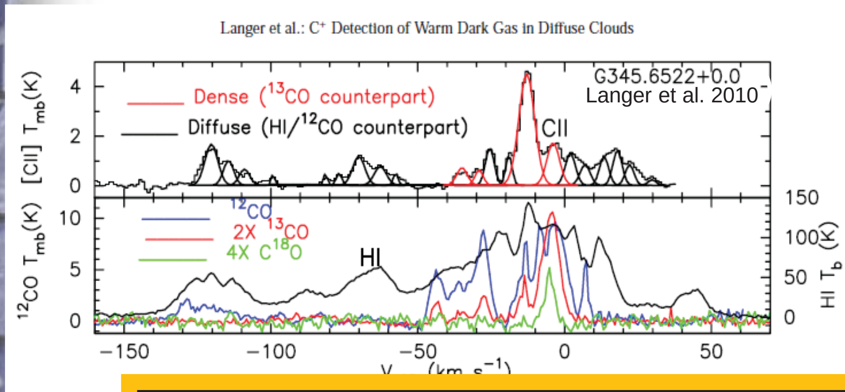

Abo

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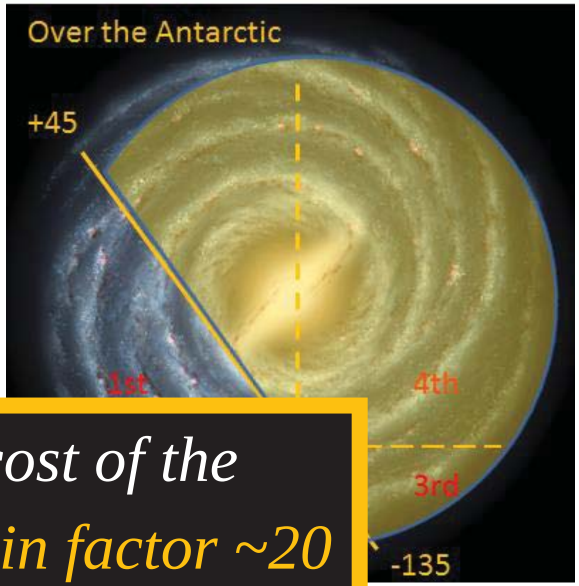
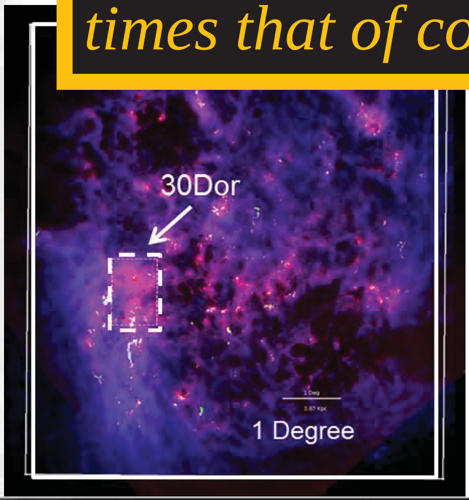
surv

GUSTO Galactic

Plane Visibility:



Greater payload capacity and Reduced cost of the ULDB yields a GUSTO Science/Cost Gain factor ~20 times that of comparable orbital mission!



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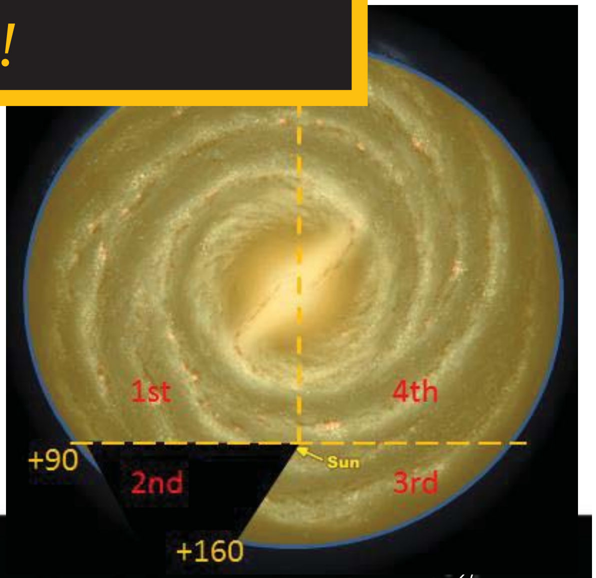

Planetary Observatory Model

- Planetary science is intending to follow an “Observatory in the sky” model
- System is an asset for the community and PI’s and missions to be competitively selected
- Requires a highly capable, robust, and modular design
  - Implies strong desire to recover safely with minimal damage
- Required or highly desired technologies:
  - Capable, strong, modular and light – weight systems
  - High in-flight science return
  - Robust landing and recovery systems

Planetary Science From Stratospheric Balloons

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- High-Altitude balloon missions offer several unique advantages for Planetary Science observations over ground, air, and sounding rocket-based observations
  - Increased transmission and lower downwelling radiance in critical portions of the electromagnetic spectrum , specifically NUV- Visible – Mid IR
  - Long duration flights provide a unique opportunity to study planetary atmospheres, and their dynamics
  - Space-like imaging – at stratospheric altitudes diffraction-limited imaging in the visible is expected
  - Highly competitive cost for science returned, particularly for long flights

Category	Total # of DS "Important Questions"	# Answered or significantly addressed	% Addressed
Small Bodies	23	10	43%
Inner Planets	39	11	28%
Major Planets	39	6	15%
Icy Satellites	75	12	16%
Mars	48	3	6%
Total	194	42	21%

A balloon based observatory is expected to address a significant portion of the planetary decadal questions

Planetary Science: Observing Advantages - Spectrum

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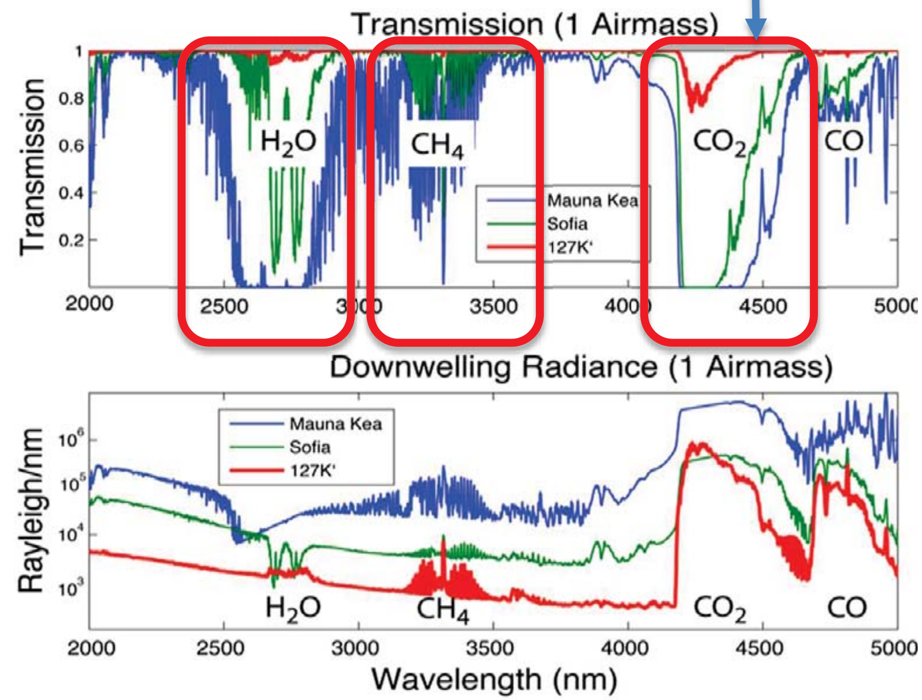
- Detecting and measuring compositions of elements on planetary bodies is key to addressing planetary decadal questions. Observations in the NUV - MIR is vital to achieving these decadal goals – This requires stratospheric altitudes and time on target

- Required technologies:
  - Precise and stable pointing (1 arc-sec or better for minutes at a time)
  - Many targets require night observations and mid latitude launches
  - Larger payloads for super pressure balloons (carry a 1m or larger telescope and instruments)
  - Float durations on the order of weeks or more

A couple examples of key observations and difference in transmission



Planetary Science: Long Duration Flights

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- Enable temporal science not practical any other way
  - Study Jupiter storms, Venus clouds & superrotation, methane or water cycles on Mars or Moon, and more
- Offer more science / dollar

Without atmospheric disturbances, space-like imaging is expected:

- For example: The Sunrise mission used Shack-Hartmann array to measure wavefront errors – "Couldn't tell that we weren't in space…" (Peter Bartoll, Sunrise PM) *
- There is 40X more atmosphere overhead at 40K ft then 125K ft. or 140X more at 14K ft (Mauna Kea)
- Image quality is critical for resolving and tracking planetary features, atmospheric dynamics, detecting and resolving small and faint bodies (comets, asteroids, Near Earth Object's, etc…

* From briefing by Young et al, 2015 and *Barthol, P; Gandorfer, A; Solanki, S; Knolker, M; Pillet, V; Schmidt, W; Title, A (2008). "SUNRISE: High resolution UV/VIS observations of the sun from the stratosphere" (PDF). Advances in Space Research* **42** *(1): 70–77. Bibcode:2008AdSpR..42...70T. doi:10.1016/j.asr.2007.09.024*.

Planetary Science Summary

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- A host of high-value planetary science can be achieved from a stratospheric balloon-based observatory
- Many planetary targets prefer views in the ecliptic (mid-latitude launches) and many require night observations
- Continuous or consistent observations spanning weeks is highly desired and a unique contribution of long duration balloons
- The planetary observatory model needs repeated / robust flights

- Required or highly desired technologies:
  - Precise and stable pointing (1 arc-sec or better for minutes at a time)
  - Float durations on the order of weeks of more
  - Capability to lift heavy payloads to ~ 35.7 km (117 kft) or more
  - Flights in mid-latitudes with night observations
  - Robust designs and reliable recovery approaches

Balloon Technologies

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- **1.6.1 Super Pressure Balloon**
  - **1.6.1.1 Extended Duration Super Pressure Balloon** -> Stable float altitude for polar and mid-latitude flights. Diurnal mid-latitude flight.
  - **1.6.1.2 Higher-Altitude Extended Duration Super Pressure Balloon** -> Stable float altitude for polar and mid-latitude flights. Diurnal mid-latitude flight.
- 1.6.2 Materials -> Lighter-weight systems will increase mass allocation for science
- **1.6.3 Pointing Systems** -> Arc second pointing from stratospheric platform.
- 1.6.4 Telemetry Systems -> Increased real-time downlink reduces burden on recovery
- ***1.6.5 Balloon Trajectory Control*** *-> Enable longer duration flights, avoid overflight of populated area, and facilitate safe termination locations*
- 1.6.6 Power Systems -> Increased power and/or reduced mass for payloads
- 1.6.7 Mechanical Systems: Launch Systems -> Remote launch of hazardous payloads/enhanced safety of launch operations
- 1.6.8 Mechanical Systems: Parachute -> Maintain strength of parachute material
- 1.6.9 Mechanical Systems: Floatation -> Recovery of extended duration missions from the ocean.